5 GHz Radio Channel Modeling for WLANs

S-72.333 Postgraduate Course in Radio Communications

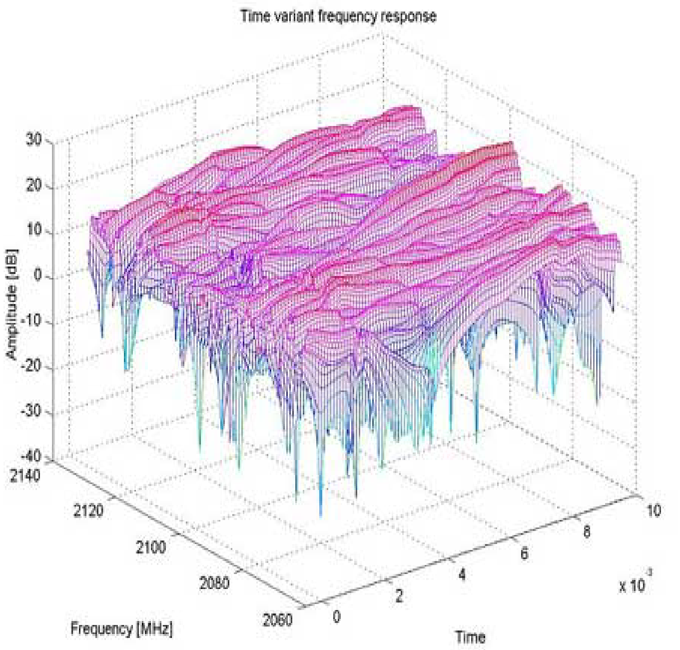
Jarkko Unkeri
jarkko.unkeri@hut.fi
54029P

Outline

- Introduction
- IEEE 802.11a OFDM PHY
- Large-scale propagation models
- Small-scale fading
- Wideband channel models for 5 GHz
    - ETSI BRAN
    - Nokia rooftop
- Delay spread simulations for 5 GHz
- Performance measurements for 802.11a
- Summary and Discussion

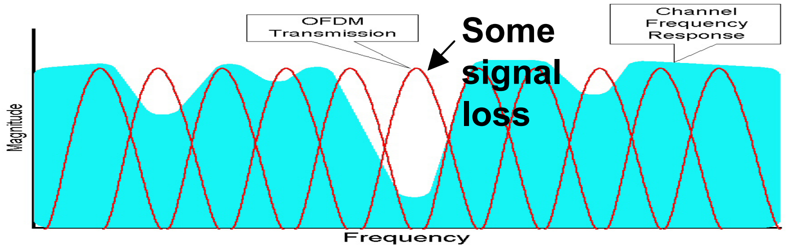
Introduction

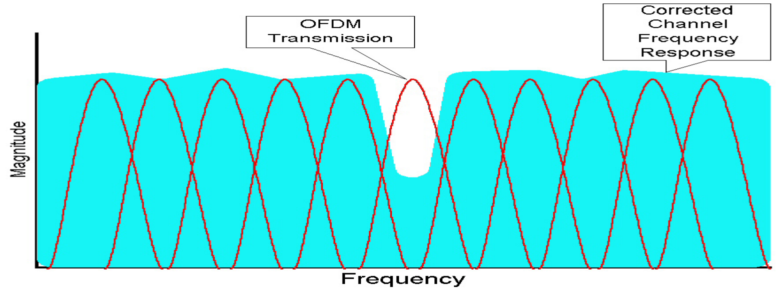
- The mobile radio channel places fundamental limitations on the performance of wireless communication systems.
- The properties of the time-varying, frequency dispersive radio channel has to be understood to be able to design optimal communication networks that have the best possible signal strength and quality for a multi-user situation
- Spatial radio channel models can give information for intelligent reception algorithms used, for example, in smart antennas



IEEE 802.11a OFDM PHY

- Frequency range (ETSI)
  - 5150-5350 MHz (indoor)
  - 5470-5725 MHz (outdoor)
- With error-correcting codes some lost carriers can be recovered



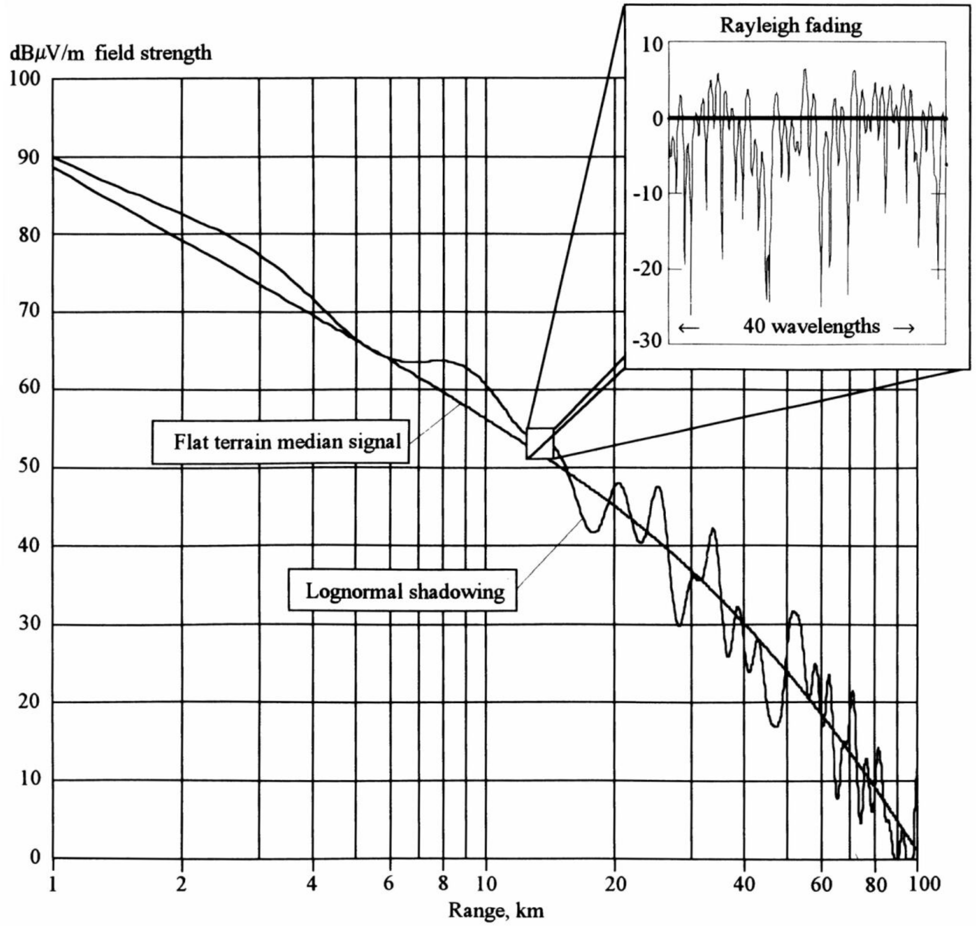


Information data rate	**6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s (6, 12 and 24 Mbit/s are mandatory)**
Modulation	BPSK OFDM QPSK OFDM 16-QAM OFDM 64-QAM OFDM
Error correcting code	K = 7 (64 states) convolutional code
Coding rate	1/2, 2/3, 3/4
Number of subcarriers	52
OFDM symbol duration	4.0 μs
Guard interval	0.8 μs[a] (T_{GI})
Occupied bandwidth	16.6 MHz

[a] Refer to 17.3.2.4.

Channel modeling

- In large-scale propagation average path loss decreases logarithmically with distance
- Large obstacles like buildings and trees cause shadowing
- With small-scale fading models more exact environmental effects and local phenomena can be modeled



Large-scale propagation models

- Variables in common large-scale propagation loss models
  - Antenna height, gain...
  - Center frequency
  - Environment type (urban, suburban, residental)
  - Connection type (LOS/NLOS)
- Typically these models are used in radio network planning for rough cell coverage estimations

Log distance path loss model with shadowing:

$$L[dB] = 10 \cdot \log\left(\frac{P_t}{P_r}\right) = L(d_0) + 10 \cdot n \cdot \log\left(\frac{d}{d_0}\right) + X_\sigma \quad .$$

d_0 is the reference distance which should be in the antenna far field. X_σ describes the shadowing.

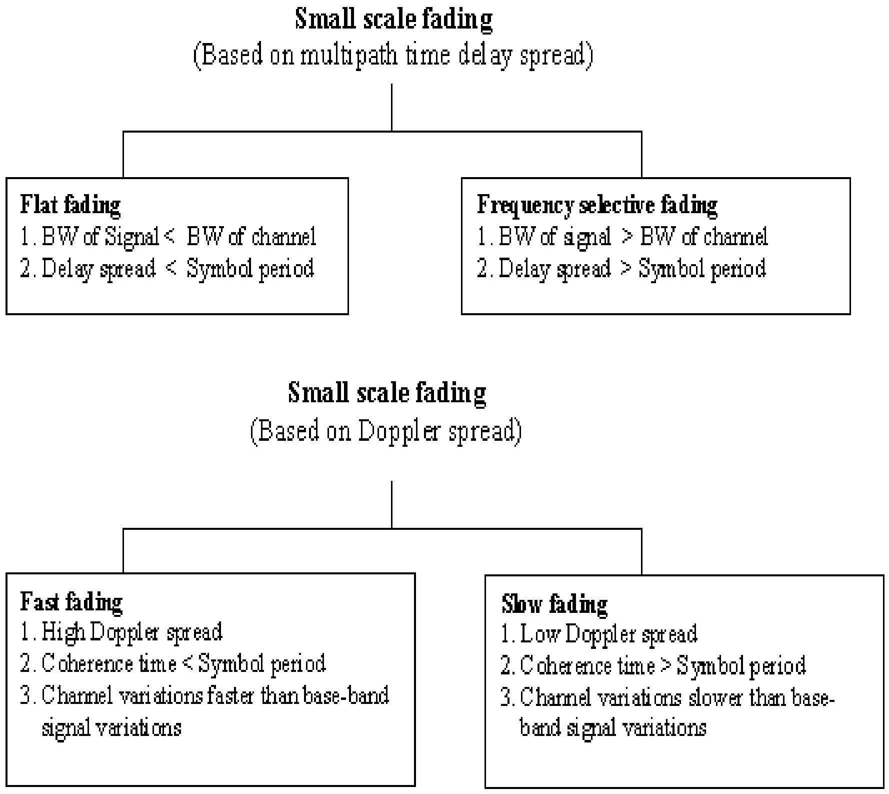
Path loss exponents
for 5 GHz

Overall	2.8-2.9	
Urban environment	LOS	1.4
	NLOS	2.8
Suburban environment	LOS	2.5
	NLOS	3.4
Rural environment	LOS	3.3
	NLOS	5.9

Small-scale fading

- Multipath propagation and Doppler spread cause small-scale fading effects to radio channel
- The three most important small-scale fading effects:

1. Rapid changes in signal strength over a small travel distance or time interval
2. Random frequency modulation due to varying Doppler shifts on different multipath signals
3. Time dispersion caused by multipath propagation delays



Small scale fading
(Based on multipath time delay spread)

Flat fading
1. BW of Signal < BW of channel
2. Delay spread < Symbol period

Frequency selective fading
1. BW of signal > BW of channel
2. Delay spread > Symbol period

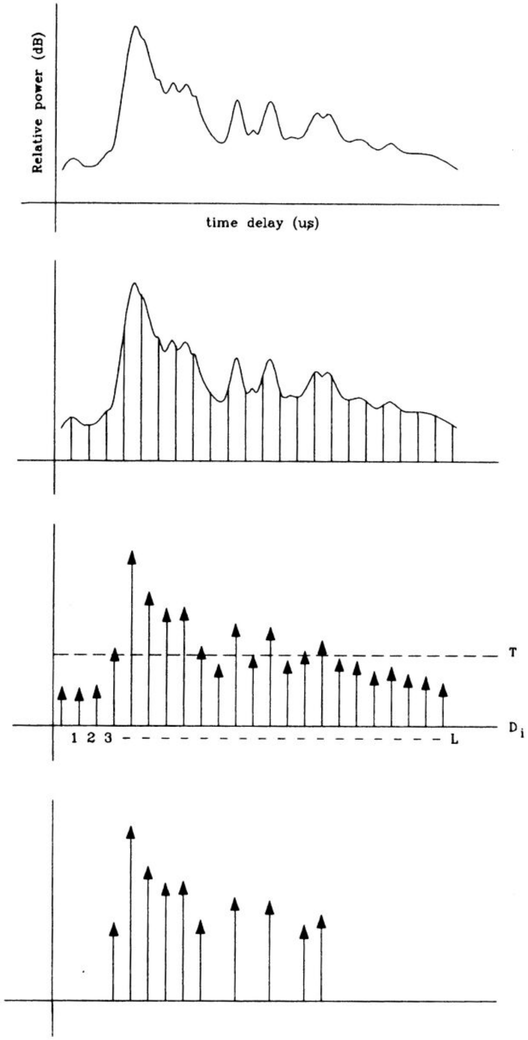
Small scale fading
(Based on Doppler spread)

Fast fading
1. High Doppler spread
2. Coherence time < Symbol period
3. Channel variations faster than base-band signal variations

Slow fading
1. Low Doppler spread
2. Coherence time > Symbol period
3. Channel variations slower than base-band signal variations

Wideband channel models

- For wideband radio systems both the path loss and the delay dispersion of the radio channel have to be characterized
- Wideband channels are typically modeled with so called tapped delay line models, where one tap includes information about signal amplitude, delay and phase.
- The signal dispersion is typically roughly defined by two statistical measures of the PDP (Power Delay Profile)
  - mean excess delay
  - r.m.s delay spread



ETSI BRAN channel models for HiperLAN2

- Models are based on an idea that HiperLAN2 Access points (AP) will be installed in hotspot areas like train stations, airports, office buildings and shopping malls
- ETSI BRAN has conducted exhaustive simulations and performance analysis for selecting the parameters

Channel model	r.m.s delay spread	Rice factor on first tap	Environment
A	50 ns	-	Office NLOS
B	100 ns	-	Open space / Office NLOS
C	150 ns	-	Large open space / outdoor NLOS
D	140 ns	10dB	Large open space / outdoor LOS
E	250 ns	-	Large open space / outdoor NLOS

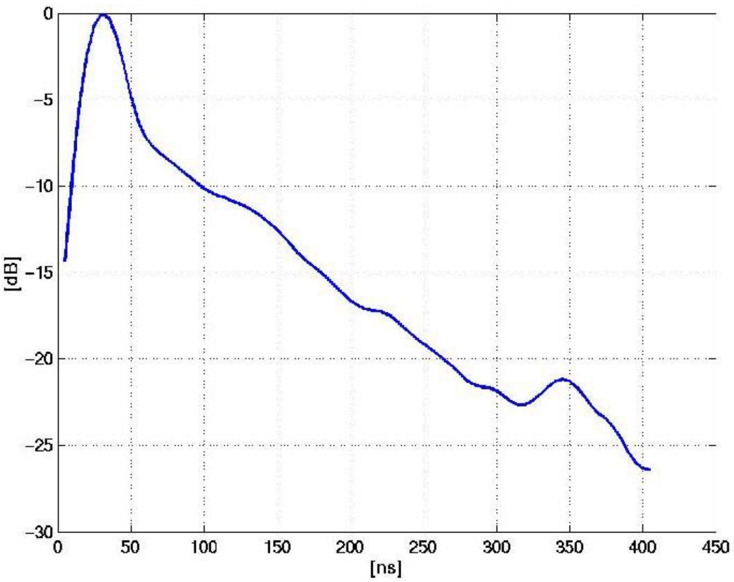
ETSI BRAN Model E

- ETSI BRAN model E with 250 ns average r.m.s delay spread
- With model E the delay spread becomes so large that it could not be fully eliminated by the guard period (800ns) of the OFDM symbol
  - ➔ ISI and ICI can not be eliminated completely which leads to degradation in system performance.

Tap Number	Delay (ns)	Average Relative Power (dB)	Ricean K	Doppler Spectrum
1	0	-4.9	0	Class
2	10	-5.1	0	Class
3	20	-5.2	0	Class
4	40	-0.8	0	Class
5	70	-1.3	0	Class
6	100	-1.9	0	Class
7	140	-0.3	0	Class
8	190	-1.2	0	Class
9	240	-2.1	0	Class
10	320	0.0	0	Class
11	430	-1.9	0	Class
12	560	-2.8	0	Class
13	710	-5.4	0	Class
14	880	-7.3	0	Class
15	1070	-10.6	0	Class
16	1280	-13.4	0	Class
17	1510	-17.4	0	Class
18	1760	-20.9	0	Class

Nokia Rooftop-model (1/2)

- The Rooftop-to-Rooftop system also utilizes OFDM in physical layer, so these measurements can also be thought to be appropriate for 802.11a
- Measurements were conducted with a radio channel sounder in the 5.1-5.5 GHz frequency band in a suburban environment
- For building a tapped delay line model the average power delay profile was calculated



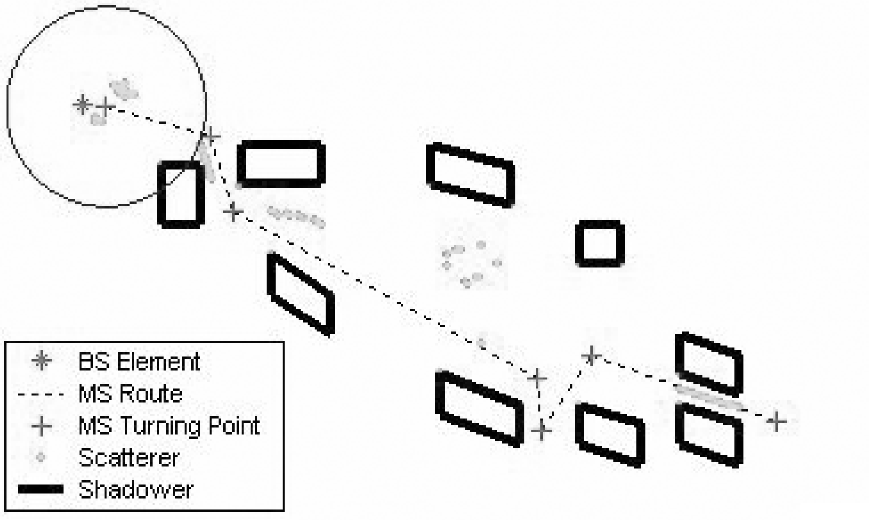
Nokia Rooftop-model (2/2)

- No clear classification between LOS and NLOS situation because of the trees between the connection
- Rice factor of 7 dB can be explained so that the LOS path is slightly blocked by trees and hilly terrain.
- The mean r.m.s delay spread was 49 ns for these measurements

Tap no.	Delay [ns]	P [dB]	Amplitude distribution
1	0	0	Rice K=7.1 dB
2	30	-6.0	Rayleigh
3	70	-10.9	Rayleigh
4	110	-13.6	Rayleigh
5	150	-17.5	Rayleigh
6	190	-20.7	Rayleigh
7	230	-24.1	Rayleigh
8	270	-28.1	Rayleigh
9	310	-28.8	Rayleigh
10	350	-32.8	Rayleigh

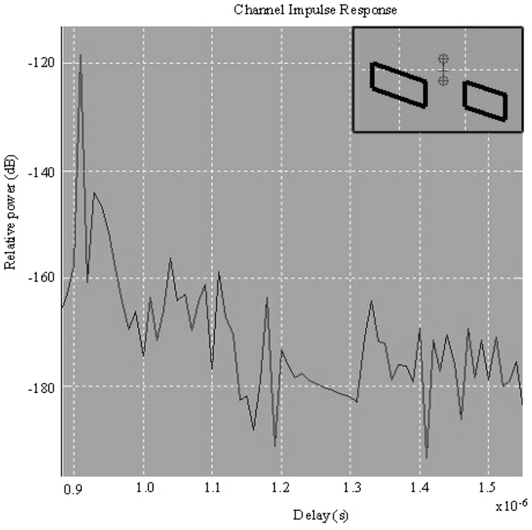
Delay spread simulations

- The delay spread simulations were performed using the PROPLab channel modeling software
- Simulations are based on geometrically based single bounce circular model
- The following variables can be defined for the simulated situations
    - Carrier frequency [MHz]
    - Sample density [per $\lambda/2$]
    - Delay resolution [ns]
    - Path loss exponent
    - Rician K factor [dB]
    - Attenuation caused by scatterers and shadowers [dB]

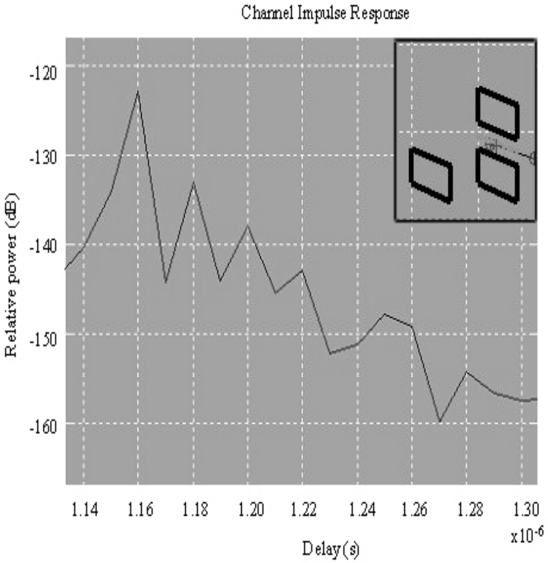


Delay spread simulation results

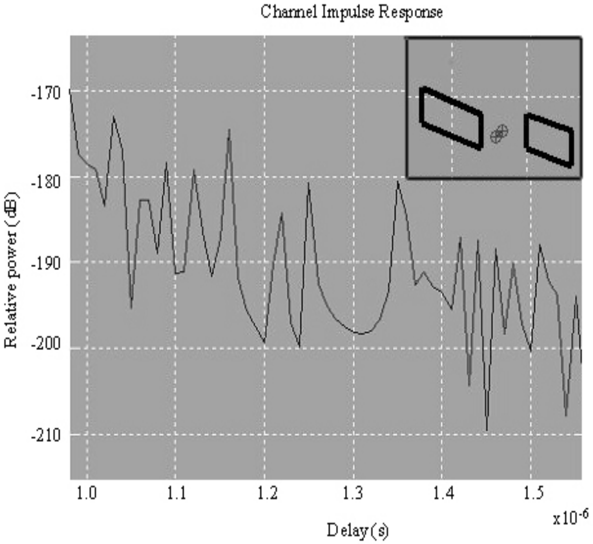
1. Direct LOS situation with as few scatterers and shadowers as possible
2. NLOS situation
3. Situation where a LOS and NLOS cannot directly be separated (Obstructed-LOS)



LOS



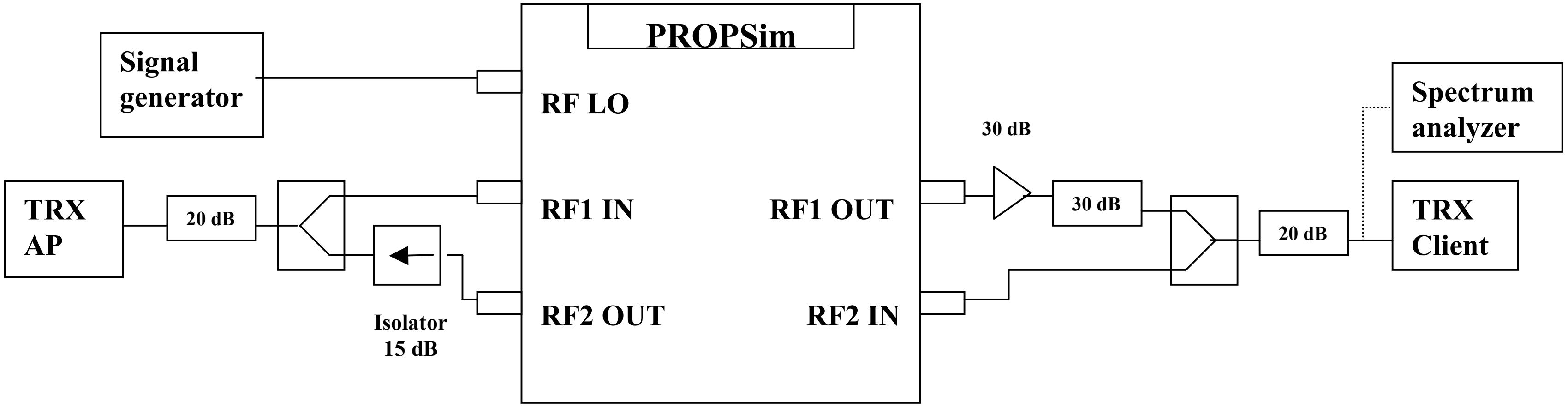
O-LOS



NLOS

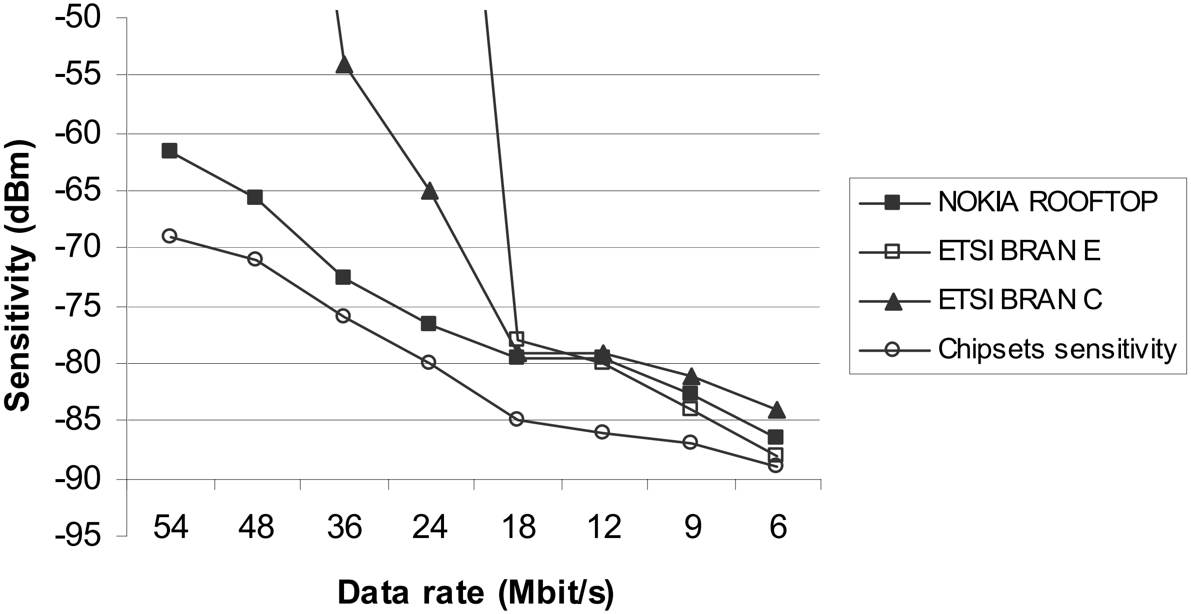
Performance measurements for 802.11a

- The performance of the 5 GHz radios in multipath environments was tested with the Elektrobit Groups PROPSim wideband radio channel simulator
- The radio system performance was measured using PER, for which the manufacturer has defined certain limits for the system to work properly



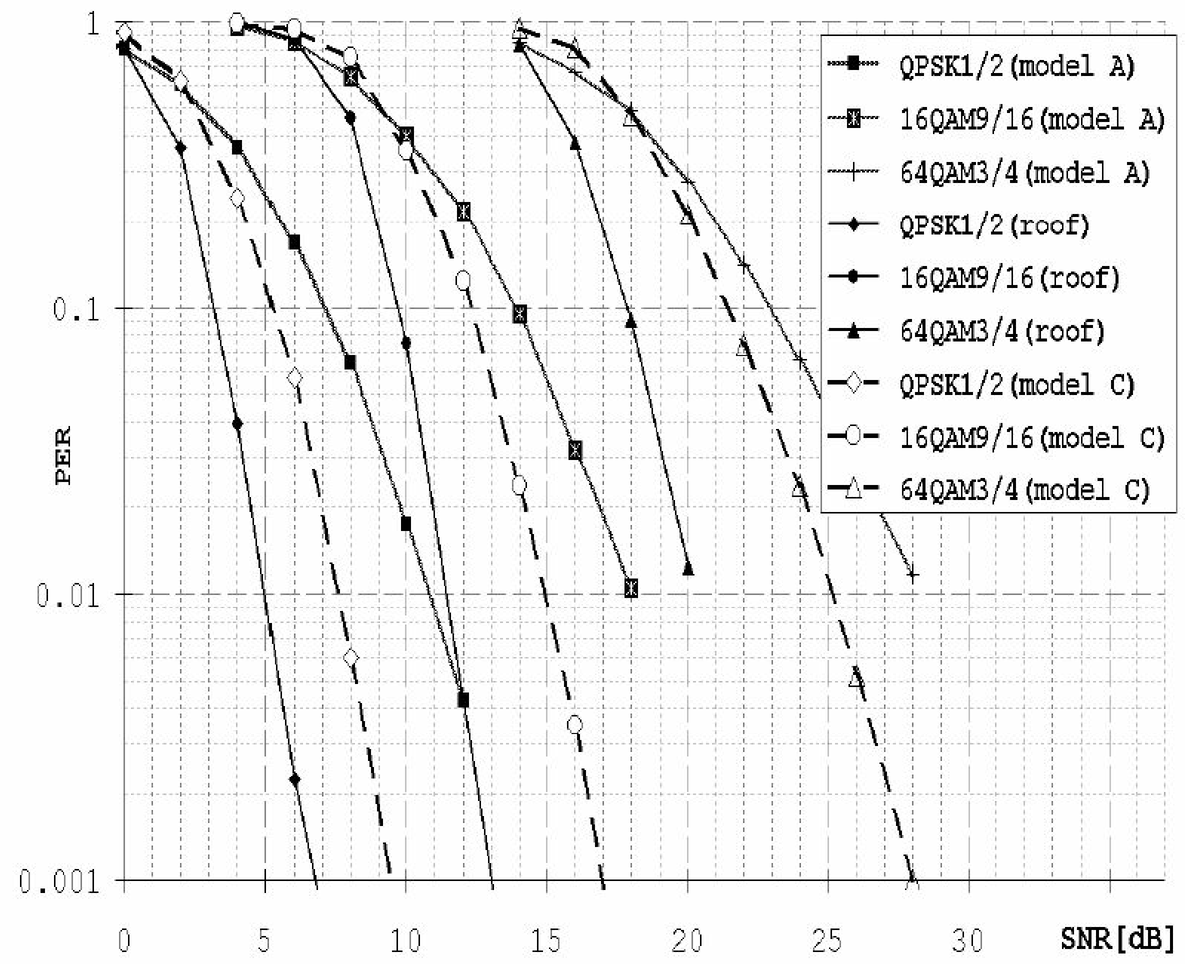
Performance measurement results for 802.11a

- Measured sensitivities for 802.11a chipset with different channel models (PER < 10 %)



H/2 Link Performance Rooftop vs. ETSI BRAN models A and C

- ETSI BRAN A
  - NLOS
  - r.m.s delay spread 50 ms
- ETSI BRAN C
  - NLOS
  - r.m.s delay spread 150 ms
- Nokia rooftop
  - O-LOS
  - r.m.s delay spread 49 ms



Summary

- There exists quite a lot of path loss exponents for 5 GHz for different environments
- Wideband channel models for 5 GHz WLAN
  - ETSI BRAN models
  - Nokia rooftop
- Multipath situations with high delay spread are tough especially for high data rates utilizing 64 QAM (54 and 48 Mbit/s)
- Rapid changes in signal strength over a small time interval are the biggest problems in NLOS situations

References

[1] IEEE Standards, 802.11a: *http://standards.ieee.org/getieee802/download/802.11a- 1999.pdf*

[2] X. Zhao, J. Kivinen, P. Vainikainen and K. Skog, ”Propagation characteristics for Wideband Outdoor Mobile Communications at 5.3 GHz”, *IEEE Journal on Selected Areas in Communications*, vol. 20, no. 3, pp. 507-514, Apr. 2002.

[3] J. Ojala, R. Böhme, A. Lappeteläinen and M. Uno, “On the propagation characteristics of the 5 GHz Rooftop-to-Rooftop meshed network”, *IST Mobile & Wireless Telecommunications Summit 2002*, 17-19 June 2002, Thessaloniki, Greece, 6 p.

[4] K. Haider and H. S. Al-Raweshidy, “HiperLAN/2 performance effect under different channel environments and variable resource allocation”*, London Communications Symposium 2002*, pp. 1-4

[5] J. Medbo, H. Hallenberg and J.E. Berg; “Propagation characteristics at 5 GHz in typical Radio-LAN scenarios”, *Proc. of VTC’ 99 Spring (Houston)*, pp. 185-189.

[6] *PROPLab V3.4 User guide*, Elektrobit Ltd (UK), Technology Transfer centre, 2003.

Homework

- List the different types of small scale fading
- Explain shortly the main reason why the path loss exponent for 5 GHz in LOS situation in urban environment is smaller than for free space loss